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Addis-Ababa, 12-16 January 1981

LOMA/ROR

# REPORT OF THE TECHNICAL PANEL OF EXPERTS ON GEOTHERMAL ENERGY

Addis-Ababa, 20-25 October 1980

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ANNEX

## A. ATTENDANCE AND ORGANIZATION OF WORK

### Opening of the Panel

1. The Technical Panel of Experts on Geothermal Energy, organized and convened by the Economic Commission for Africa, met at Addis Ababa, Ethiopia, from 20 to 25 October 1980 within the framework of the preparatory activities for the United Nations Conference on New and Renewable Sources of Energy to be held at Nairobi, Kenya, in August 1981.

2. The Panel, held in parallel with two other panels, namely on hydropower and on biomass (including fuelwood and charcoal), was opened on 20 October 1980 by the Deputy Executive Secretary of ECA. After welcoming the participants, the Deputy Executive Secretary emphasized the importance of the contribution they could make as African experts to the Panel and to the success of the United Nations Conference on New and Renewable Sources of Energy to be held at Nairobi in August 1981.

3. He broadly outlined the need to develop indigenous energy resources within the context of the current world energy situation and described the preparatory activities for and objectives of the United Nations Conference to be held at Nairobi.

4. The Deputy Executive Secretary reviewed Africa's energy resources potential and utilization. With respect to geothermal energy, he emphasized the existence of numerous potential areas on the continent and the need to develop them as currently only an insignificant part of that potential was tapped or at the initial development stage.

5. Further, he stressed the role that new and renewable sources of energy would play in the over-all economic development of African countries.

6. Referring to the agenda of the Panel he drew the experts' attention to the need to consider drawing up a concrete programme for the development and utilization of energy resources in Africa including the definition of a common policy, particularly at that time when African efforts were concentrated on the establishment of a New International Economic Order.

7. He concluded that the expertise of the participants and their recommendations would be a sound basis for the Intergovernmental Preparatory Meeting on New and Renewable Sources of Energy in Africa to be held at Addis Ababa from 12 to 16 January 1981.

### Election of officers

8. The Panel unanimously elected the following officers: Dr. Ghebru Woldegheorghis as Chairman, Dr. S.B. Ojiamibo as Vice-Chairman and Mr. Molla Belaineh as Rapporteur.

Attendance

9. The Panel was attended by seven participants, in their individual capacities as experts in geothermal energy, from Djibouti, Ethiopia, Kenya, Uganda, the United Republic of Cameroon and the United Republic of Tanzania (annex).

B. AGENDA

10. The Panel adopted the provisional agenda with minor modifications. The agenda adopted was as follows:

1. Opening of the Panel
2. Election of officers, adoption of the agenda and organization of work
3. Geothermal energy potential in Africa
4. Situation, trends and prospects for geothermal utilization in Africa
   (a) Power production
   (b) Other uses
5. Major obstacles to the development of geothermal energy utilization in Africa
6. Ways and means to overcome the constraints at national, regional and internationa levels
7. Definition of a common policy in the geothermal sector for African countries within the framework of the United Nations Conference on New and Renewable Sources of Energy to be held in Nairobi, in August 1981.
8. Consideration and adoption of concrete recommendations to expand geothermal energy utilization in Africa; the role of geothermal energy in Africa within the context of the current world energy situation
9. Other business
10. Consideration and adoption of the report of the Panel
11. Closure of the Panel

C. ACCOUNT OF PROCEEDINGS

Geothermal energy potential in Africa and status of activities

11. A document prepared by ECA, outlining the present status of geothermal resources development in certain African countries, was introduced by a representative of the secretariat.

12. The document indicated that the best zones for geothermal resources development were located in East Africa where there were many still active volcanoes and other geothermal manifestations, all linked to the tectonics of the Great African Rift Valley, extending from the Red Sea in the north to Mozambique in the south through the territories of Djibouti, Ethiopia, Kenya. Uganda, the United Republic of Tanzania the Great Lakes Region and Mozambique.

13. Mention was made of promising sites with geothermal potential in West and North Africa, such as the Mount Cameroon and Adamaona regions in the United Republic of Cameroon, the region around Lake Fagribine in Mali, the Tibesti region in Chad, certain areas located between the Volta basin and the Senegal basin and some stretching from the Canary Islands to the Libyan Arab Jamahiriya through Morocco, Algeria and Tunisia. The Comoros and Madagascar were also considered as promising areas.

14. The representative of ECA secretariat reviewed briefly the status of activities carried out in geothermal energy in those countries with geothermal potential from which no experts were attending the panel.

15. The experts made statements on the geothermal activities carried out in their respective countries as follows.

16. In the United Republic of Cameroon, although no practical assessment of geothermal potential had been made, reconnaissance work had been done and an inventory of hot springs and other thermal manifestations had been drawn up in the area situated between the Coast and Adamaoua. The hot spring were sampled for geochemical analysis to determine the mineral components and surface temperatures were measured.

Chemical analysis of the hot springs had shown that their waters had therapeutic properties similar to those of some thermal sources in the central massif of France.

17. In the United Republic of Tanzania some studies of thermal springs had been conducted during the years prior to independence by members of the Mineral Resources Division and fairly complete summaries of previous geothermal investigations in the country had been provided by James and Walker. Over 70 thermal springs had been located and analysed and most of them had been shown to be intimately associated with the position of the Rift Valley or with fault traces. The temperature of the springs was up to 72°C at the surface and up to 98°C at a depth of 35 m at the Maji Moto hot springs near lake Manyara.

18. At least two and perhaps three volcanoes had been active in the past, namely Ol Donyo Lengai and Meru. Kilimanjaro (Kibo) appeared to have shown only fumarolic and solfataric activity. A report on recent volcanic activity in the Rungwe region had not been confirmed. Evidently Ol Donyo Lengai was the most active volcano in the country and seemed to have been active from the upper Pleistocene (13 eruptions were noted in previous centuries and 7 since 1900; the last eruption was in 1966). From Meru, volcanic activity had been reported in 1877, 1886 and in October and December 1910, but the first two reports were somewhat unclear. Since 1910 the volcano seemed to have been in a solfataric stage. There had, however, been extensive volcanism in that area and, in the vicinity of Meru, there were a great many craters, some of them with crater lakes. It seemed highly probable that a high subsurface temperature existed in the above-mentioned volcanic areas. It should be noted that although the volcanoes had not shown any signs of activity for thousands of years, they could not be considered as extinct since they might well be dormant. It was possible for a volcano to have a life-span of millions of years.

19. Previous studies on geothermal resources in the United Republic of Tanzania had focused on areas with young volcanism in various parts of the country and on the east Rift Valley of which two arms crossed through the United Republic of Tanzania. The western arm formed the depression in which lake Tahganyika and Lake Eyasa were situated. The eastern arm of the African Rift Valley, the Gregory Rift Valley, went through the Lake Natron regions, Lake Manyara, the Singida region, and attenuated south of Dodoma. Large areas in the northern part of the Gregory Rift Valley, i.e., the area of Lake Natron and Lake Eyasi to Mount Kilimanjaro, were covered by Tertiary volcanic rocks. The Rungwe volcanic complex in the Mbeya region, which was located within the Western Rift Valley in the south-western part of the country covered about 1200 sq km. Faulting, associated with rifting, characterized the Lake Rukwa and Songwe River Basin. At that time, one of the Rungwe volcanoes was reported to be active.

20. In the United Republic of Tanzania hot springs were known to exist in three different areas, i.e., the area in the vicinity of and around Lake Natron, Lake Eyasi and Lake Manyara, an area in the Mara region about 70 km east of Musoma and the area in the Mbeya region in the Lake Rukwa and Songwe River Basin in the south-western part of the country. Fumaroles were also known to exist in the Mount Kilimanjaro and Mount Meru craters.

21. According to available data, the United Republic of Tanzania showed great geological potential for geothermal energy exploration. However, the country had the intention of continuing its reconnaissance study in greater detail in order to delineate a viable field for geothermal energy production.

It must be borne in mind that the electricity supply system of the United Republic of Tanzania was under the control of the Tanzania electricity supply company (TANESCO) and most of the demand was concentrated in the coastal region. That area was supplied by a hydropower plant at Kidaty which had displaced the former diesel and gas turbine installations as part of the Government's policy to maximize the utilization of indigenous energy resources. The coastal electricity system had recently been amalgamated with the Arusha-Moshi network to form one major interconnected grid supplied by hydropower stations.

22. The discovery of a substantial geothermal field in the vicinity of Lake Natron, which exhibited many surface manifestations of geothermal activity, would allow base-load power to be fed into the TANESCO main grid system at its nearest point at Arusha. The acquisition of a substantial block of geothermal plant by that network would complement the operation of the hydro plant and ensure greater reliability of electricity supplies during dry years.

23. Helium gas occurred in abnormally high concentrations in a number of hot springs in the United Republic of Tanzania. It constituted up to 19 per cent of the evolved gas in such hot springs as the Nyamosi springs of the Musoma district, near the border with Kenya, and up to 17.5 per cent of the evolved gas in the Maji Moto area on the western shore of Lake Manyara. A third area which had a large proportion of helium was the Mponde spring in the Manyaghi hot springs group where 10.2 per cent of the evolved gas was helium. The gas could be extracted as a by-product during the production of geothermal energy.

24. In conclusion, in the United Republic of Tanzania, the majority of geothermal manifestations indicated the existence of low-temperature geothermal resources, which could be used for industrial purposes as they were a cheap form of energy. There were fumarolic activities in the craters of Ol Donyo Lengai and Meru. A high subsurface temperature was therefore likely to exist in the vicinity of those volcanoes although no thermal manifestations were visible on the surface. That might be caused by the fact that the surroundings of the volcanoes were covered with thick strata of pyroclastic material and that the groundwater table was low.

25. There were also at indications that high-temperature geothermal resources might exist which could be used to generate electrical energy. The Maji Moto in Musoma district, Songwe in Mbeya district and Mtagata in Karagwe district contained high-temperature geothermal resources at a certain depth.

26. From the reconnaissance studies conducted throughout the country, the United Republic of Tanzania had been shown to have favourable conditions for geothermal energy exploitation. It was envisaged that a pilot projectmight be initiated in the Mbeya region where a geothermal field had been identified as having temperatures of above 200°C. It was

also the policy of the country to explore the possibility of starting similar projects in the other areas mentioned for both rural and urban electrification.

27. In Kenya, there were a number of areas in the Rift Valley which had active surface geothermal manifestations but only three of these had been surveyed, namely Lake Bogoria, Eburru and Olkaria. Around the shores of Lake Bogoria there were a number of hot and boiling springs and some fumaroles, but geothermal activity in the other two areas was confined mainly to widespread fumaroles, which had often been used to supply the local population with water by condensing the steam in sloping galvanized pipes and collecting condensate at the lower end. Steam from shallow wells was also used at Eburru as a source of heat for drying pyrethrum flowers.

Kenya had no natural fuel resources in the form of coal or oil. The rivers had highly seasonal flow patterns, which made their exploitation for hydropower generation expensive. The fact that there was a large source of geothermal power available relatively close to Nairobi, the main electrical load centre, was therefore very attractive. Early in the 1950s a consortium of companies, which included the E.A. Power and Lighting Company, had been formed to carry out exploration drilling. At that time Lake Bogoria was in a remote area and building suitable access roads would have been very expensive. With no suitable source of water supply for drilling purposes at Eburru and with only limited funds available a decision had been taken to drill at Olkaria.

28. A hole designated X-1 had been started in May 1956 using a percussion rig and, as indicated in drilling reports by D.L. Marriott, progress had been slow due to continual loss of circulation, caving formations, and drilling mishaps. Frequently drilling was delayed by lack of water which had to be pumped through at $2\frac{1}{2}$ in. line some 6 km long with a total lift of just over 200 m to the drill site. On a number of occasions dry steam at low pressure blew from the hole, notably at 380 m, but this was then cased off.

Three strings of casing, $12\frac{1}{2}$, 8 5/8 , and 6 in., were run into the hole. At a depth of 380 m, below the 6 in. casting, drilling continued at 5 1/8 in. diameter with a rotary rig. Temperatures recorded during the percussion drilling reached 120°C at 370 m, but were lower than this during the rotary drilling. Hole X-1 had been eventually abandoned at a depth of 502 m in January 1958. Before this, however, work with the percussion rig had started in August 1957 on a second hole, designated X-2 some 2 km north of X-1 at an elevation of 1975 m, and drilling was generally more rapid than at X-1. Rotary drilling started after a 12 in. casing was set to 54 m and an 8 3/4 in casing to 200 m. Progress had again been delayed because of a loss of circulation and various drilling mishaps, but a depth of 942 m had been reached in July 1958. A perched water zone between 55 m and 170 m was cased off but it was thought the cementing of the casing here was poor and that there was continuous leakage of cold water down the annulus between the hole

and casing into the much hotter zone lower down, where there was a second water reservoir with a rest level of 342 m. After X-2 had been drilled to 942 m, several attempts to bring it into production by air-lifting were made. None of these efforts had been successful, however, and work had eventually stopped in March 1959.

29. Following the abandonment of X-2, interest in further geothermal exploration work during the early 1960s had been very low and plans were made to harness the Tana river for hydropower. However, in view of the very high capital costs involved, interest had been revived in further geothermal work, and in 1967 a Wenner configuration resistivity survey was carried out in the Rift Valley between Lake Bogoria in the north and Olkaria in the south. That survey showed a number of resistivity anomalies and recommended exploration drilling. Eventually a request had been made in 1969 by the Kenyan Government to the United Nations for assistance in financing a much larger exploration programme. It was originally intended that work should be concentrated in the Lake Bogoria area, but it was later decided to include all three geothermal areas, Olkaria, Eburru, and Lake Bogoria.

30. A project to be jointly financed by UNDP and EAPL, acting as the Kenyan Government's agents, had been agreed upon, in which the United Nations undertook to supply experts in various specialized fields, and EAPL provided local counterpart staff to be trained during the course of the project. The United Nations also financed contracts involving "offshore" expenditure while EAPL provided all local support staff and the necessary services. At the end of 1970, a start was made and field work was conducted during 1971 and 1972.

31. After carrying out the predrilling programme of geothermal exploration, consisting of detailed geological mapping, infra-red survey, ground temperature survey, resistivity surveys, gravity survey, microearthquake surveys and hydrogeochemical surveys, the final phase of the geothermal exploration project had started in the Olkaria area, based on the positive results obtained from hole X-2.

32. In preparing the drilling programme, the advantages of drilling an 8 3/4 in. final diameter hole over a slim hole were considered worthwhile, in spite of the extra expense, so that there would be a minimum of delay in exploiting any significant discovery of steam. It was also decided that in view of the very low water rest level which were likely to be found, and to prevent the possibility of well damage due to mud caking, it would be advisable to drill in the reservoir with foam. The information available about foam drilling in geothermal reservoirs was, however, rather sparse. It was therefore decided that, as a safeguard, it would be advisable to provide sufficient water at each site to be able to drill with water should the need arise. For the first drill site (Olkaria 1), therefore, it was necessary to construct a 6-in. pipeline from Lake Naivasha some 12 km long and rising to a height of over 250 m above the lake level. The water was pumped in three stages to a 500,000 gallon reservoir after which there was a gravity feed to the drill site.

A modified T12S drilling rig was transported to Olkarja in August 1973 and drilling started on Olkaria 1 on 12 October 1973.

33. Olkaria 1 had been sited at the intersection of the well-defined north-south fault running through the area, with a secondary east-west fault in order to ensure the possibility of drilling through a zone of good permeability. There were a number of fumaroles close to the site of Olkaria 1 and there was also some microearthquake activity in the area.

The drilling programme had called for 20 in. casing to be set at 30 m, 13 3/8 in. casing at about 250 m, and 9 5/8 in. casing when the reservoir had reached an anticipated depth of 600 m. The fluid used down to 602 m was conventional bentonite mud and the early stage of drilling were characterized by zones of frequent loss of circulation and low hydrostati pressure. Below 602 m stiff foam was used and penetration rates were good but it was found that the standard roller bearing tricone rock bits had suffered excessive rapid wear of the bearings, probably as a result of poor lubrication and cooling.

The formation drilled had consisted mainly of tuffs and lavas with a number of sedimentary lake beds. It was apparent that the hole intersected two aquifers, the upper one between 140 m and 400 m, which was cased out, and the lower one from 618 m to the bottom of the hole. Downhole temperatures were very low and the maximum recorded was 126°C at 1,000 m depth. A number of attempts had been made to air lift the hole into production by pumping compressed air through a 2 in. tube to a depth of 970 m, but none of these were successful and the hole had eventually been abandoned at a depth of 1,003 m in the middle of March 1974. Eruption was not achieved owing to low permeability and low temperature.

After failing to obtain high enough temperatures in Olkaria 1, a cold water step-injection test had been conducted to try to determine some of the reservoir characteristics. Injection rates varying from 200 to 1,000 l/ min were used over a period of about 6 hours and a pressure recorder was placed at 698.5 m to measure pressure changes during and after the injection. A pressure increase of 10.5 bars was recorded during the test, suggesting low permeability and large drawdown. Further calculations showed that the well had a transmissivity value of 4 sq m/day, specific capacity of 2.4 - 4.8 l pm/m and permeability of 34 millidarcies (md).

34. Those figures were below those obtained from X-2. following an analysis of the cause of failure at Olkaria 1 it was decided to move toward the north-east of the prospect for drilling Olkaria 2. The chemical data obtained from fumaroles in that area gave indications of high temperatures and resistivity surveys were also favourable, although there was no obvious geological fault close by. It was also thought the water rest level would be shallower. Drilling had started on 13 April 1974 with a 26 in. hole using mud to a depth of 40 m when 20 in. casing was cemented, after which drilling continued with foam at 17 1/2 in. diameter to a depth of 230 m, where 13 3/8 in. casing was set. Because the hole was drilled with foam and circulation zones were not sealed with cement plugs, it was not known whether a good cement bond was achieved with the 13 3/8 in. casing. Drilling then continued at 12 1/4 in. diameter with foam to about 590 m where it became

apparent that either the hole was caving or the foam had insufficient lifting capacity to bring cuttings up to the surface. Casing at 9 5/8 in. diameter was therefore set to 595 m and drilling continued at 8 3/4 in. diameter with foam. Weak formations were again encountered below 600 m and some cement plugs were set to stabilize the hole. Below 600 m aerated mud was used as a drilling fluid, which improved the return of cuttings to the surface, but at about 650 m there was some evidence of dry steam production. It was considered that continued drilling with mud could effectively seal the formation, so an aerated water/foam mixture was used as drilling fluid and circulation return with cuttings was satisfactory. As the hole was drilled deeper than 1,000 m, however, re-establishment of circulation after a rock bit change became more and more difficult and sometimes it was difficult to regain circulation even after adding a drill pipe. This problem was partly overcome by the use of jet sub in the drill string and the hole was drilled to a depth of 1,350 m, when a 7 in. slotted liner was run in from 600 m to the bottom of the hole.

Downhole pressure and temperature measurements in Olkaria 2 had been taken during and after drilling. The most stable temperature run indicated that temperatures at the bottom of the hole could be near 280°C. The hole was originally thought to penetrate a dry steam zone, in which case near-constant temperature with depth and pressures close to 32 bars (abs) would be expected. That did not seem to be the case and after several flow tests and downhole measurements, the hole was found to produce a mixture of steam and water although the dryness factor was much higher than other known wet wells (about 60 per cent steam).

Flow tests had been conducted using lip-pressure pipes with different diameters to obtain flow characteristics. Initially, when operating at a well-head pressure of 6 bars (abs), the well produced about 50 tonnes of steam per hour which is equivalent to about 5 MW. But later tests showed long-term steam production of nearer 30 tonnes per hour.

35. With indications of good output from Olkaria 2, it had been decided to drill two more holes as offsets, so that the three well locations would be at the corners of a triangle with sides of about 200 m. Both these holes were drilled with little trouble, Olkaria 4 taking only one month from start to finish. The 26 in. hole was drilled with mud, after which foam was used for the 17½ in., 12½ in., and 8 3/4 in. holes. It was found from experience that a mixture of foam and water gave the best results for lifting cuttings to the surface, although difficulties were frequently experienced in establishing circulation after rock bit changes.

It would be noticed that the 9 5/8 in. casing was set at 700 m in both Olkaria 3 and 4. A 7 in. slotted liner was run into Olkaria 3 from 690 m to the bottom of the hole. Olkaria 4 was completed without a liner so that it could be determined if the hole would produce satisfactorily unlined. The well discharged for about a month and then collapsed, so a liner was set.

After completion of both Olkaria 3 and 4 the wells were shut in for several days to allow heating of the formation, after which they were blown vertically through 6 in.

flow pipes. Flow rates and well-head pressures were both very low, in sharp contrast to the results which had been obtained from Olkaria 2 less than 200 m away. As the drilling contract was complete and the crew had left the site, it was not possible to carry out remedial work with the drilling immediately, and it was therefore decided to carry out a water injection programme in both wells to open existing structures and to create new ones.

Olkaria 3 and 4 wells were drilled to 1,357 and 1,661 m respectively, and had similar geologic formations. As in Olkaria 2 the sediments occurred mainly above 700 m and had thus been cased out. Below the production casings, tuffs formed about 40 and 35 per cent in Olkaria 3 and 4 respectively, while the rest were lava. Most of the lava within this lower zone was trachyte and all were altered to some extent. Pyrites began to appear from 250 m. while sulfur started to appear from 670 m; magnetite was not seen until after 1,200 m. The contacts of lavas and tuffs displayed thin horizons of brick red (perhaps steam-baked tuffaceous material) and the drilling crew noticed fluid inflow and pressure rise whenever such layers were encountered.

Temperature inversions and maximum cooling zones during water injection seemed to coincide with the contact zones between lavas and tuffs. It was inferred that the contact interfaces might be the permeable zones available in that area and such thin brick-red zones (called old land surfaces in Kenyan geological literature) were known to be the aquifers for many shallow water wells in the Rift Valley.

Downhole temperature and pressure profiles posed several interpretative possibilities. Runs taken before the wells were flow tested, showed a heating rate of about 3°C per day, temperature inversions at about 1,050 m above sea level, and temperature maxima at about 1,158 to 1,100 m above sea level. Both occurred either within tuff or at the contacts between altered lava and relatively fresh lava. Runs, taken some hours after water injection, showed maximum cooling of the wells below 700 m with Olkaria 4 showing a maximum temperature drop at 850 m (1,100 m above sea level). The heating rate after the injection test averaged about 7°C per day, double the rate before injection. Well-head pressure in Olkaria 3 also improved after this. Runs taken after flow tests showed the disappearance of the temperature inversions indicated in the earlier runs. However, a later run in Olkaria 3 showed a slight inversion at 900 m and a temperature of 271°C at 1,050 m, and Olkaria 4 showed no inversion and 286°C at 1,300 m The Olkaria 4 temperature plot followed the theoretical boiling temperature curve from 500 m downward.

36. The geothermal drilling programme was still going on and so far 16 wells had been drilled at depths varying from 900 m to 1,685 m . Of those, the majority were productive, some of them yielding 90 per cent dry steam. Spacing between wells was 200 - 250 m and the output varied from zero to 3-3.5 MW. It was found that 1.5 MW per well was economical under Kenyan conditions compared to other energy sources. The average temperatures in the geothermal fields currently developed in Kenya (1 x 1 km) were 280°C (maximum 304°C); the drysteam wells had a temperature of 235 - 245°C.

37. Based on the results of that work, the first geothermal power plant capable of producing 15 MW of power was under construction at Olkaria, south of Lake Naivasha and would be commissioned in July 1981. The second 15 MW plant would be commissioned in July 1982. Production from the area was to be progressively increased while studying characteristic reservoir changes during production. This area had an estimated minimum potential of 170 MW.

38. Currently, multipurpose utilization of geothermal resources was being envisaged such as the production of potable water and agricultural uses along with a programme for well reinjection.

39. Although geothermal activities in Kenya had received some external technical assistance they were progressively being taken over by the country itself. All the scientific crew were Kenyans and apart from six foreigners on the drilling site, all the drilling crew was made up of Kenyans. A second rig had just arrived and use would be made of one rig in drilling exploratory wells in other areas around Olkaria.

40. As far as the Republic of Djibouti was concerned, geothermal activities had been started before independence by BRGM. On the basis of reconnaissance work, three areas had been selected, namely Lake Abbé, the Hanlé plain and Lake Assal.

41. In the Hanlé area (NW), 2000 sq km had been surveyed mainly in the volcanic and some sedimentary formations located in a graben at the cross-road of three great faults (Gulf of Aden, Rift Valley and Red Sea). Hot springs and fumaroles had been identified proving the geothermal interest of the area.

42. In the Lake Abbé area (SW), the tectonics were similar to the Hanlé plain area and th potential sector covered some 2,000 sq km . Tensional tectonics were favourable for a convective fluid circulation; moreover the lateral graben faults were much deeper resulti in the occurrence of basaltic rocks. Hot springs and fumaroles were frequent in the area

43. Surveys undertaken in the Lake Assal area had confirmed the existence of a high temperature anomaly, close to the surface, along with the presence of impermeable volcani rocks. Given its envisaged potential, the Lake Assal area had been retained as most promising. Moreover, this area was close to the town of Djibouti, a significant consumer of electric power. Geological, geochemical, hydrogeological, geophysical and petrologica surveys had been carried out in the area and based on their results, two exploratory well had been drilled; one with a total depth of 1,146 m which proved to be productive (130 tons/h of watersteam mixture at 259° C and 6 bars). The content of steam in water was some 20 per cent which corresponded to 25-30 tons/h of steam capable of supplying about 1.5-2 MW of power through a 5 in. casing).

44. Since 1978, three projects had been undertaken: extensive testing of the producing well, consisting of an observation of the pressure evolution, output, steam rate, salinity, etc. In co-operation with UNDP; extension of geothermal reservoir surveys in the Lake Assal area, and determination through geophysical methods of the tectonic hidden lines in order to select future drilling sites, in co-operation with BRGM; inventory of geothermal resources of the Lake Abbé area and Hanlé Plain area which would result in a prefeasibility study prepared in co-operation with an Italian company, Aquater.

45. The main aim of geothermal energy development in the Republic of Djibouti was to supply the town of Djibouti with electricity, since it was the only energy source available in the country. Other uses of geothermal resources were also envisaged, particularly for industrial purposes (extraction of salt, gypsum treatment for building industries, etc.).

46. In Ethiopia, the first geothermal exploration had been carried out by the Institute of Geological Surveys as early as 1967 in collaboration with Pisa University and the Italian National Research Council. It had resulted in a recommendation to carry out geothermal investigation in the Afar Depression.

47. In the light of that the survey had carried out a first stage geological and thermal mapping in the Rift Valley lakes in 1969. It was immediately followed by a United Nations assisted geothermal investigations project in early 1970. That project was the earliest extensive geothermal reconnaissance and exploration programme covering the whole of the Rift Valley and the Afar Depression. The investigations covered a total area of approximately 160,000 sq km . The studies done were geological mapping, geochemistry, hydrogeology, infra-red survey and an extensive inventory of hydrothermal manifestations. The report concluded that there existed an enormous geothermal potential in the country. Delineation and selection of sites for further detailed work was also made.

48. The sites selected were, in the order of their preliminary prospect:

(a) Tendaho Graben in the Afar Depression;

(b) Dallol in the Afar Depression;

(c) The Lakes Region in the Rift Valley.

Although Tendaho Graben had been given first priority in the recommendations of that report, Northern Langano was chosen for the continuation of further detailed work because of its proximity to the capital and the national transmission grid system. The geological survey continued exploration consisting of geological mapping at a scale of 1:50,000, geophysical survey using dipole-dipole

methods and geochemical sampling and resampling of hydrothermal manifestations to study their evolution, through time. Shallow wells were also drilled to study the temperature gradient and the general stratigraphy. Technical assistance from the United Nations at this stage, had been limited to an expert or two together with the supply of geophysical instruments. The geothermal areas of Ethiopia could be divided into two, namely the main Ethiopian Rift Valley, and the Afar Depression.

49. The geothermal area in the Lakes Region of the Rift Valley had been at that time divided into three prospect areas:

(a) Lake Langano area;

(b) Gorbetti Caldera area;

(c) Northern Lake Abaya area.

The three areas had more or less similar geological characteristics, with formations of the pleistocene and recent volcanic activity consisting of mainly peralkali rhyolitas and partly fissural basaltic flows. The heat source was anticipated to be either regional or from residual magma chambers of the above volcanism. There was intense tectonic activity resulting from tensional forces. Lakes originated in the tectonic depressions and volcano tectonic collapses. Lake sediments resulting from the shrinkage of the lakes were thought to constitute part of the Cap rock. The geophysical survey had delineated areas of low resistivity that could possibly coincide with geothermal reservoirs at a depth in the order of 1,500 m. Geochemical thermometry indicated subsurface temperatures in the order of 200°C to 250°C and in some cases even higher. So the positive results of those studies led to a United Nations sponsored technical review meeting in January of 1980 that culminated in the selection of deep exploratory and production-sized well sites for drilling.

50. Funds had already been acquired for the drilling phase, with a major portion of them from EEC and a minor part from the United Nations complemented by Ethiopian Government funds, to cover consultancy and expert costs. The drilling of nine wells was scheduled to start in the Lakes Region in February 1981. The Lake Langano area had been chosen as the first site and, depending on the outcome, drilling in the other site would follow. However if the wells at Langano proved positive, all the planned nine wells would be drilled here. It was anticipated to start the construction of a power plant in stages.

51. Exploration studies were also being carried out in the Afar Depression. As in the Rift Valley, the geothermal areas of the Afar Depression had also been subdivided into various prospect areas. The most promising of these were Tendaho Graben and Dallol. Geologically the Afar Depression was a triple junction, where the Red Sea, Gulf of Aden and the Ethiopian Rifts met. Recently some areas of the Afar Depression had been identified as spreading zones, undergoing

processes similar to oceanic ridges. Many earth scientists now believed that a mantle plume lay under the Afar. As a result there was a regional anomalous heat flow and active volcanism induced by spreading plates.

52. The Tendaho Graben, located in the Central Afar Depression, was the most prominent geothermal site. It was between 40 and 50 km wide and 70 to 100 km long. A systematic study in the form of a prefeasibility project had been carried out here through Italian technical co-operation in 1979 and 1980. The project was in two phases, with the first phase consisting of geological mapping at 1:50,000 scale, detailed hydro-geochemical analysis of all thermal manifestations and preliminary geo-electric survey using Schlumberger methods. After having narrowed the area to the most promising sites with the results of the first phase, further detailed geophysical (gravity, magnetics and geo-electric), geological, geochemical and shallow well drilling investigations were carried out in the second phase in an area of 3,000 sq km . Preliminary conclusions were that the area was positive with a geothermal reservoir at a depth of approximately 1,000 m with a temperature in the order of 250°C. Preparations were being made to continue with the next phase of exploration.

53. In conclusion, the country was well aware of its vast geothermal resources and was also trying to promote the multipurpose uses of geothermal energy, including tourism and agro-industries. At least one use, bathing and thermal therapy had been known in the country for centuries. Training of national staff inthe field of geothermal energy was also being promoted.

54. In 1971 a preliminary investigation for geothermal anomalies had been carried out in Uganda after realizing that conditions existed which seemed to favour the existence of a geothermal field. The purpose of that survey was to initiate a geothermal development programme to be undertaken by the Geological Survey and Mines Department after consultations with members from the Ministry of Planning and Economic Development and Uganda Electricity Board. The first phase of the programme agreed to by members, was to be a preliminary survey and the preparation of a report noting particular areas for more detailed investigation for the consideration of a United Nations expert who was to come shortly to Uganda. If it was found warranted, steps would be taken to set up a geothermal exploitation programme in collaboration with UNDP.

55. In Uganda, thermal waters were found both in Precambrian and Tertiary rocks. Most thermal springs issued from the joint planes of granitic gneisses of Precambrian age along an up-lift axis some 30 km east of the Albertine Rift Valley. This axis connected with a volcanic field to the south, the Katwe volcanic field. It was, however, interesting to note that the number of hot springs decreased in volcanic regions and they tended to emerge at rift

boundaries. It was clear that hot springs in Uganda tended to occur in areas associated with earth movements. This was especially true in the Rift Valley where some faults were still active.

56. The western Uganda area where most of the hot springs occurred had been divided into three geothermal potential areas: the Katwe volcanic field to the south, the Buranga field at the foothills of the Ruwenzori mountains and the Kibiro field in the northern part of the Rift Valley near lake Albert. Of the three, the Katwe volcanic field was the most promising. The area was famous for its explosion craters and saline lakes. The waters were rich in Na, K, $HCO_3$, Cl and $SO_4$. Total dissolved salts had been determined at up to 100,000 - 350,000 ppm.

57. Although hot water manifestations were not numerous in this field, the Na X atomic ratio gave a postulated subsurface temperature of 230°C. Geologically the rocks were volcanic tuffs, agglomerates and sandy clays. Structurally, the field was situated in a fault block terrain, a condition which was favourable to the formation of a good geothermal field.

58. The Katwe geothermal field had been earmarked as a top priority in exploration for geothermal energy firstly because it was located only 35 km from the terminus of a 132 KV hydro transmission line at Kasese. Secondly, waste heat from the generating plant could be profitably utilized to concentrate valuable mineral brines located in the crater lakes in the area. Presently, a salt industry exploiting the Lake Katwe brines was in operation and a geothermal energy plant in the area could serve as a vital alternative source of power should the hydroelectric power supply fail.

59. Further studies in the Buranga and Kibiro area were also envisaged although those areas, because they were sparsely populated and remote, were at a disadvantage. That meant that the power produced would not have ready consumers.

60. Following the preliminary studies carried out by the Geological Survey of Uganda, a United Nations expert on geothermal energy had been requested by the Uganda Government in 1971. His work was based on the recommendations of the preliminary survey. His report (McNitt 1971) was in the form of a project document for requesting United Nations or bilateral assistance for further geothermal exploration in Uganda. This report endorsed the three areas which had been identified in the preliminary studies and stressed that there existed a high geothermal potential in those areas. The project would soon be submitted to UNDP.

61. Finally UNDP was currently planning a multisectoral project for the Development of Kagera River Basin countries, Rwanda, Burundi, the United Republic of Tanzania and Uganda. It was the feeling of the Uganda Government that a specific project for the exploration of geothermal resources in that region should be included in that multisectoral programme.

62. The locations of the various geothermal anomalies in Uganda were far from the main hydroelectric schemes. Thus, harnessing the geothermal systems for local production of electricity would contribute greatly to the rapid electrification of rural areas.

63. A first attempt had been made to assess the geothermal potential of southern Nigerian sedimentary basins from a study of subsurface temperatures from the log records of over 1,000 oil wells. The geothermal gradient varied from 1°F/100 feet at the centre of the Niger Delta to 3°F/100 feet in the cretaceous rocks to the north, which were affected by the santonian folding and magmatic episode in the Benue trough. The low geothermal gradient in the Niger Delta suggested very little potential for geothermal resources development in that area, whereas the steeper gradients to the north defined an area with better prospects.

64. In Algeria, many thermal indications were located in the north - eastern part of the country. That area was considered the most favourable for a high enthalpy geothermal development programme. Nevertheless, implantation of small-scale units for producing electricity from hot springs (100°C) might be considered well before the development of high-enthalpy zones. An exploration programme had been carried out in Algeria more than 10 years ago and had been recently reactivated (geophysical survey). The University of Annaba was presently engaged in R&D activities and was working on a medium-enthalpy project.

65. In Tunisia, several areas were known to have medium-and low-enthalpy geothermal resources, particularly in the north-western part of the country, the Zaghouan-Cap Bou area and Gabes region. The presence of high-enthalpy fields was not excluded. Research and Development programmes were carried out by the Office National des mines by a small geothermal group of scientists. Geological mapping of geothermally potential areas, hydrogeochemical sampling and analyses, as well as studies of deep well logs were currently carried out by the same office and sites were selected for low-and medium-enthalpy projects. Research was carried out by the University of Tunis in geology, geochemistry and geophysics.

66. In Morocco, several areas of major interest for low-and medium-enthalpy had been identified, as follows: the Rif/Atlas region and the great basins of the west, Kuncitra (Gharb) and southern plains. Reconnaissance surveys for geothermal potential had been carried out in the 1960s and 1970s.

67. For financial reasons, assessment of geothermal potential in Madagascar was limited in scope for the time being. Although it was known that a large number of warm springs were spread throughout the eastern part of the country, no area had been yet delineated as a high priority zone for detailed exploration. However, a reconnaissance survey of all warm springs had been planned to

provide geochemical information in order to select of priority areas. The Malagasy Government was assisted in performing the survey by UNDP as regarding the purchase of equipment and contracting of consultancy services. Work had begun on the project in 1979 and would be completed by the end of 1980. On completion of the survey, a technical team would review the results and make recommendations for further work.

Technological and economic problems related to geothermal activities for power production

68. The Panel of experts unanimously agreed that as far as the predrilling phase for geothermal development was concerned, there were no special technological problems.

69. In the exploratory drilling stage, however various problems were encountered as follows:

(a) Technical problems connected with the process of drilling itself (pipe drilling sticking, loss of circulation, proper choice of drilling fluid, cementation, fishing, etc.);

(b) Acquisition of equipment and material supplies from overseas resulting in a drain of foreign exchange;

(c) Difficulties in building the infrastructure on the selected sites, particularly when areas were remote and sparsely populated;

(d) Lack of qualified manpower and data interpretation equipment and the related difficulties of interpreting the acquired data;

(e) Problems in getting suitable effluent disposal systems.

70. Although it could be generally stated that the economics of geothermal energy were generally favourable, specific costs were difficult to discuss without reference to specific cases.

71. In general, the parameters met in geothermal systems were so numerous that a general rule was difficult to draw up. The temperature increased with depth and costs would increase as a result, although this might eventually be offset by the lower specific energy cost. Of course, there were convective systems and high-enthalpy products might be found at/or close to the surface in which case costs would decrease significantly. The other variable was the flow rate which depended on permeability or fracturing of the rocks and hence influenced the power output of the wells.

Problems of exploration and exploitation, composition of the water (minerals and gas content), associated with corrosion were other variables which made the economic assessment more difficult.

72. Therefore, in order to have an idea of geothermal energy economies, it should be emphasized that when good geothermal fields were found, independently of their enthalpy value, they were of very high economic interest and the energy they produced could be competitive with fossil fuels, oil in particular. As an example, high-enthalpy plants existing elsewhere produced electricity at the production cost of $US 0.02 to 0.10 per kWh, whereas medium-enthalpy plants produced electricity at a cost of $US 0.15 to 0.25 per kWh.

73. It should be noted that exploration for geothermal sources represented a significant share of the cost, and that a large differential existed between the cost of drilling a large diameter exploration hole and the cost of predrilling geoscientific investigations. As an example the current cost of a full-size exploratory well in USA (about 23 cm in diameter) was about $US 500-600 per metre, or about $US 1 million per hole drilled to a depth of 2,200 m.

74. A typical 50-power plant in a fluid-dominated geothermal system required an average of 12 producing wells (7 to 8 wells in a dry-steam field).

75. At the current rate of success in geothermal exploration (about 40 per cent), which was higher than the rate of success in petroleum exploration, about $US 10 million were being spent on exploration drilling for the discovery of one geothermal reservoir. The cost of predrilling geoscientific investigations might be estimated at some 12 to 15 per cent of the drilling expenditure (this is the case in USA).

Other uses of geothermal resources

76. The multipurpose use of geothermal resources was becoming the predominant type of geothermal resources utilization, because, compared to single-purpose development, multipurpose use offered the following advantages:

(a) It was more economical and might offer additional social benefits (such as heated swimming pools, therapeutic uses, space heating, etc.;

(b) It usually allowed higher efficiency in energy use;

(c) It often allowed the utilization of associated resources (such as water for agriculture, minerals and gases).

77. The location and resource characteristics were important for geothermal resources in general and especially so in the case of multipurpose utilization.

Hot water, the main component of most types of geothermal resources, could not be transported economically over distances exceeding 50 km. Thus, hot water as a heat source had to be used, near to its source. The same applied to steam, which required that a geothermal power station should be located nearby. Electricity could be transmitted over long distances and valuable minerals extracted from geothermal water could also be transported over long distances, but in each case the first processing had to be done near the field.

78. Given those restraints, the economic needs and the economic potential of the area around the geothermal field were decisive factors in the multipurpose utilization of geothermal resources.

Thus, if the geothermal fields were located near areas where heat was required for processing agricultural or forestry products or for heating houses and hospitals, industrial buildings and schools or near industries which could utilize the various components of geothermal resources, then the multipurpose utilization of geothermal resources was not only feasible but also economically attractive in practically all cases.

79. The non-electric production of steam and hot water was even more profitable given the currents level of oil and coal prices. It was obvious therefore that in the future industries would want to exploit geothermal fields in order to produce low-cost steam or hot water. They would develop small fields if they existed near the plants and would be attracted to large fields, just as industries moved to hydropower sites at the beginning of the modern era of electricity.

80. Geothermal hot water could also be used for refrigeration and air conditioning.

81. In semi-arid or arid areas, the large volumes of water produced by geothermal resources could make important contributions to food and fibre production in a variety of ways.

82. A geothermal field was indeed the only resources which could provide the necessary water supply, heat supply and $CO_2$ supply for year-round greenhouse farming. In certain cases some fertilizers might also be extracted from geothermal resources. Geothermal fields produced enough water even for larger-scale farming and, in areas which lacked fresh water, geothermal desalination could provide desalinated water at a reasonable cost.

83. Geothermal sites might be popular tourist attractions in addition to providing the therapeutic benefits, thereby providing the country with much required foreign exchange (e.g. the Sodere site and hot baths in Ethiopia, Lake Bogoria springs, Hellsgate fumaroles in Kenya, the Sempawa site in Uganda, etc.).

84. Geothermal resources might also prove to be profitable as a source of mineral by-products such as lithium, rubidium, cesium, boron. strontium, helium gas, and sodium, potassium, magnesium and potassium salts, etc..

85. High concentrations of lithium, rubidium, cesium and boron had been found in thermal carbon dioxide waters of mountain-folded regions, in thermal waters of the regions of recent volcanism and in hot brines of artesian basins. High concentrations of strontium were characteristic only of artesian basins.

86. Rare elements accumulated mainly in sodium chloride and calcium chloride ground waters. Low values of the Na/Li and K/Ca ratios were typical of waters containing rare metals. Those ratios might be an exploration index of thermal water.

87. The problem of the industrial extraction of rare elements from thermal water should be approached in two ways: first, through the preparation of a raw material base, that is, by finding thermal water and calculating water resources;and second, through the development of technological methods of extracting rare elements from thermal water in different geochemical classes.

Major obstacles to geothermal energy utilization in Africa and ways and means to overcome them

88. The policy makers of many African countries were not aware of the benefits of geothermal resources. That could be overcome by an exchange of information on geothermal resources among African countries, possibly with the assistance of ECA.

89. Even when countries were aware of the existing geothermal potential, they lacked adequate funds and manpower to develop the resources. Accelerated financial and technical assistance from international and bilateral sources should be sought.

90. It was most difficult to exploit geothermal resources in Africa in areas which were sparsely populated or unpopulated, where the usual infrastructure did not exist, where markets for the variety of resource components were difficult to find and when the geothermal resources were located deep inside the country in areas of difficult access.

Role of geothermal energy in Africa

91. The development of geothermal energy in Africa had become particularly attractive owing to the uncertainty of future oil supplies coupled with the regular increases in the price of available oil supplies and their effect on the balance of payments of some African countries. Since geothermal plants operated on an indigenous new and renewable energy resource, foreign exchange costs were minimal. Because there were no fuel costs involved in operating a geothermal power plant, operating costs would remain relatively stable.

92. Compared to its closest rival as an indigenous renewable source of energy, hydropower, capital investment and operating costs were lower. While the cost of geothermal exploration might be high, geothermal exploitation was particularly suited to the installation of relatively small power generating units in stages. Thus the development of geothermal resources in any area could be based on an ongoing programme consisting of the regular installation of small power plants whose size might be increased in step with the increase in consumer demand for electricity. Technically geothermal power installations were not complicated and extremely simple to operate. Deprived areas could be electrified very easily through the development of geothermal resources.

D. RECOMMENDATIONS

93. The Technical Panel of Experts recommended that all African countries should evaluate the potential of various energy sources, in particular geothermal, with a view to formulating national energy policies. The assessment should include an evaluation of the supply and demand of energy needs and an inventory, in the case of geothermal, of all natural thermal manifestations.

94. The Panel further recommended that policy makers in African countries should be made aware of the benefits to be derived from geothermal resources. Co-operation was recommended in technological information and exchange of qualified personnel in the field of geothermal energy among African countries, particularly with those who have reached an advanced stage of geothermal exploration and development.

95. After an extensive exchange of views, the Panel of Experts agreed on a model exploration and development programme comprising the following phases:

- The reconnaissance phase would include a reconnaissance survey and inventory of geothermal manifestations within the member countries followed by the drafting of a project document with the assistance of a technical expert in the field of geothermal energy. The Panel felt that this reconnaissance phase should be carried out by qualified scientists from the national geological survey department

- The basic exploration phase would be made up of two stages: first, geological mapping, hydrogeological survey and geochemical analysis of the prospect areas as determined during the reconnaissance phase; and second, geophysical surveys complemented by shallow well drilling in the target areas delineated on the basis of the results of the first stage surveys.

- The Panel of Experts noted that technical and financial assistance was needed for that phase.

- In view of the fact that the next phase involved many more intensive financial and technological commitments and risks, the experts recommended that a technical review meeting, involving national experts, relevant national institutions including policy and decision makers and foreign experts should be held. That meeting must review findings of the data collected during the first two phases and recommend whether or not to proceed with the next phase including the selection of drilling sites.

- The exploration drilling and feasibility study phase would involve the drilling of exploratory wells and an evaluation of reservoir capacity followed by a feasibility study.

96. In order to encourage the speedy development and exploitation of that new, renewable and indigenous source of energy, the Panel of Experts recommended that Governments should do their utmost to secure loans on a soft term basis.

97. The Panel of Experts further recommended the expansion of the Energy Resources Unit of ECA with geothermal experts in order to provide advisory services to member countries, at their request and eventually establish regional and/or subregional geothermal development centres.

98. The Panel recommended that, in so far as possible, national institutions in one of the member countries should be strengthened, so as to provide training facilities for technicians, professionals and artisans in the field of geothermal energy development, both for national personnel and personnel from other African countries.

99. The Panel recommended that Governments involved in geothermal activities might wish to invite specialized institutions interested in plate-tectonics and seismic activities related to geothermal phenomena to set up measurement stations in the African Rift Valley.

100. Taking into consideration the fact that geothermal energy was one of the cheapest forms of energy to exploit and could be used for purposes other than supplying electric power, the Technical Panel of Experts on geothermal energy recommended that African Governments should, during the United Nations Conference on New and Renewable Sources of Energy to be held at Nairobi in August 1981, reaffirm their willingness to assess and exploit immediately the existing geothermal resources in their countries in line with previous recommendations made by OAU and ECA meetings as stipulated in the Lagos Plan of Action and endorsed by the OAU Heads of State.

## E. CONSIDERATION AND ADOPTION OF THE REPORT OF THE PANEL

101. After considering and amending the draft report, the Panel of Experts adopted this final report including the recommendations.

F. CLOSURE OF THE PANEL

102. The Technical Panel of Experts on geothermal energy then joined with the two other panels, on hydropower and biomass, and reviewed the final recommendations. The three panels were closed by a representative of the ECA secretariat.

ANNEX

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